The What, How, and So-What of Soil Compaction

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Soil compaction is the process whereby soil particles are pushed closer together at the expense of decreasing the amount of air space. At the same time, the diameters of the pores between the soil particles are made smaller. While this is easy to understand, what is often not understood is that compaction is a **process,** not an end point. One cannot say that a given soil is "compacted" whereas another soil is "not compacted." There is no definite threshold of bulk density or penetration resistance for example, beyond which a soil suddenly changes from "non-compacted" to "compacted".

When will a soil compact under the stress of a tire or tillage implement? Soil will compact when the strength of the soil is less than the load being applied to the soil. Relative soil strength can be estimated rather easily with a soil penetrometer. But there are some very important "ifs". Soil strength is very dynamic, and is very sensitive to soil water content, which fluctuates daily. A relatively wet soil with a moderately high bulk density may give a relatively low penetrometer resistance reading. Another soil (or same soil at a different location) with the same bulk density, but now relatively dry will give a much higher penetrometer resistance reading. So did the 2 soils actually have different levels of compaction or was it just because they had different water contents at the time of measurement? Penetrometer resistance readings can be corrected for differences in bulk density, and soil water content, but this requires extensive data sets and sophisticated laboratory measurements. A better alternative may be to make all penetrometer measurements at a common water potential/content, perhaps field capacity. But this approach gives no indication of the dynamic physical resistance being encountered by plant roots at various times during the growing season.

In addition, soil texture affects penetrometer resistance, as does the design of the penetrometer itself, and the way it is used. Never the less, extensive field and lab data suggests that root growth will probably not be significantly impaired if penetrometer resistance is not higher than 200 pounds/square inch. That may seem like a high reading but, contrary to rigid metal probes, plant roots have the ability to turn and take the path of least resistance through soil.

Bulk density can also be an indicator of degree of soil compaction, but again with caution. A low bulk density value may indeed indicate a low degree of compaction; or it may be due to differences in soil texture and/or soil water content. Generally speaking, plant growth will probably not be significantly impaired if soil bulk density is not higher than 1.3 g/cm^3.

Tillage and wheel traffic are the main causes of man-imposed soil compaction. Under modern agriculture, wheel traffic is by far the more serious cause. When tractors and implements are relatively small and of low weight, soil compaction is pretty much a function of the pounds/sq.in. (psi) being applied to the soil surface by the wheel or track. Extensive field data suggests that if the pressure applied to the soil surface is not higher than 10 psi, soil will not be compacted more than currently exists in most fields. Thus, most tractors and field equipment (with exception of harvesting and transport equipment) will likely not cause compaction deeper than 8-10 inches, especially if tracks or low inflation pressure tires are used. This doesn't mean, however, that compaction won't be a problem; but rather it will be sufficiently shallow that it can be ameliorated mechanically.

Figure 1 clearly shows that even shallow compaction may not be ameliorated under natural conditions. Using Curve "E" as a reference, Curve "A" represents the typical increase in bulk density caused by the wheel traffic of normal farming operations during the year (excluding harvest/transport equipment). If no fall tillage is done, and bulk density is measured the following spring in last year's wheel track (Curve "B"), we see that freezing and thawing decreased the bulk density only slightly (from 1.6 to 1.5), and only in the surface 3 inches. Reduced fall tillage (curve "C") was more effective than natural forces, and to a deeper depth. Fall plowing (Curve "D") was the most effective way of ameliorating soil compacted in the surface 8-10 inches by wheel/track traffic.

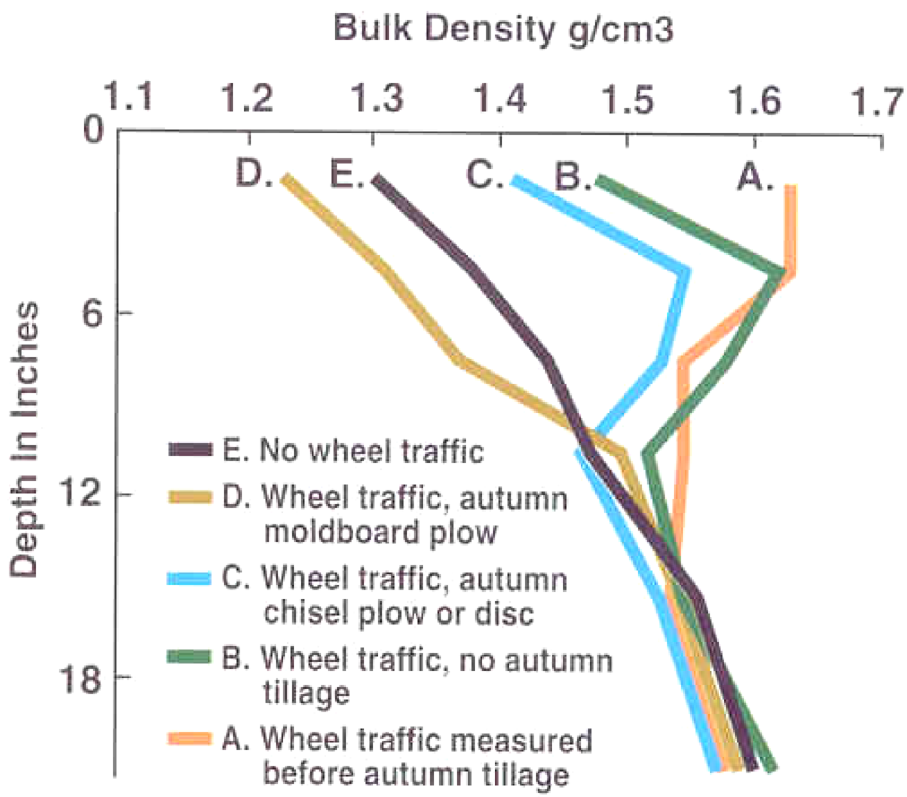

Figure 1. Effect of wheel traffic, tillage, and freezing on bulk density.

With respect to soil compaction deeper than normal tillage depths, we have to consider not only the pressure being applied on the soil surface by the wheel or track (psi), but also total weight being carried by the wheel or track. Theoretically, if the "foot print" of tires/tracks could stay proportional to the increase in weight, the behemoth machinery of today would not cause any deeper compaction than smaller equipment. But the size and weight of current harvest and transport equipment has increased faster than industry's ability to increase tire/track foot print.

Tracks and low inflation pressure tires are a step in the right direction. But the data in Table 1 clearly suggests a concern when axle loads of common harvest and transport equipment (often on wet, weak soils) can be 4-5 times greater than that allowed on a concrete highway.

Table 1. Axle load of common field machinery.

Equipment	Axle Load (tons/axle)
2-wheel drive tractor	5
6-row empty combine	10
600 bu graincart (one axle)	20
12 row full combine	24
1,200 bu grain cart (one axle)	40
Concrete highway	8-12

Long-term field experiments were conducted in Minnesota as part of an international study in which plots were compacted by wheel traffic carrying axle loads of 5, 10 and 20 tons/axle. Experience has shown that 5-ton axle loads normally do not cause subsoil compaction. Figure 2 shows corn yield in southern Minnesota as affected by a one time application of a 20-ton/axle load in the fall of 1981, typical for corn harvest and transport equipment . This treatment significantly increased bulk density, penetrometer resistance and hydraulic conductivity to a depth of at least 24 inches. Immediately after the heavy axle load traffic, the plots were plowed to a depth of about 10 inches to eliminate surface layer compaction, and all machinery from that time on was limited to a 5-ton axle load or less.

In 1982, the first growing season after the 20-ton axle load, corn yield was decreased by 30%. It then appeared that freezing and thawing over the next 4-5 years gradually decreased the original subsoil compaction as yields returned to normal. But in 1988, corn yield was decreased about 15 % by the 20-ton axle load applied in the fall of 1981. 1988 was the driest year on record at this site, and apparently sufficient subsoil compaction remained to adversely affect roots as they

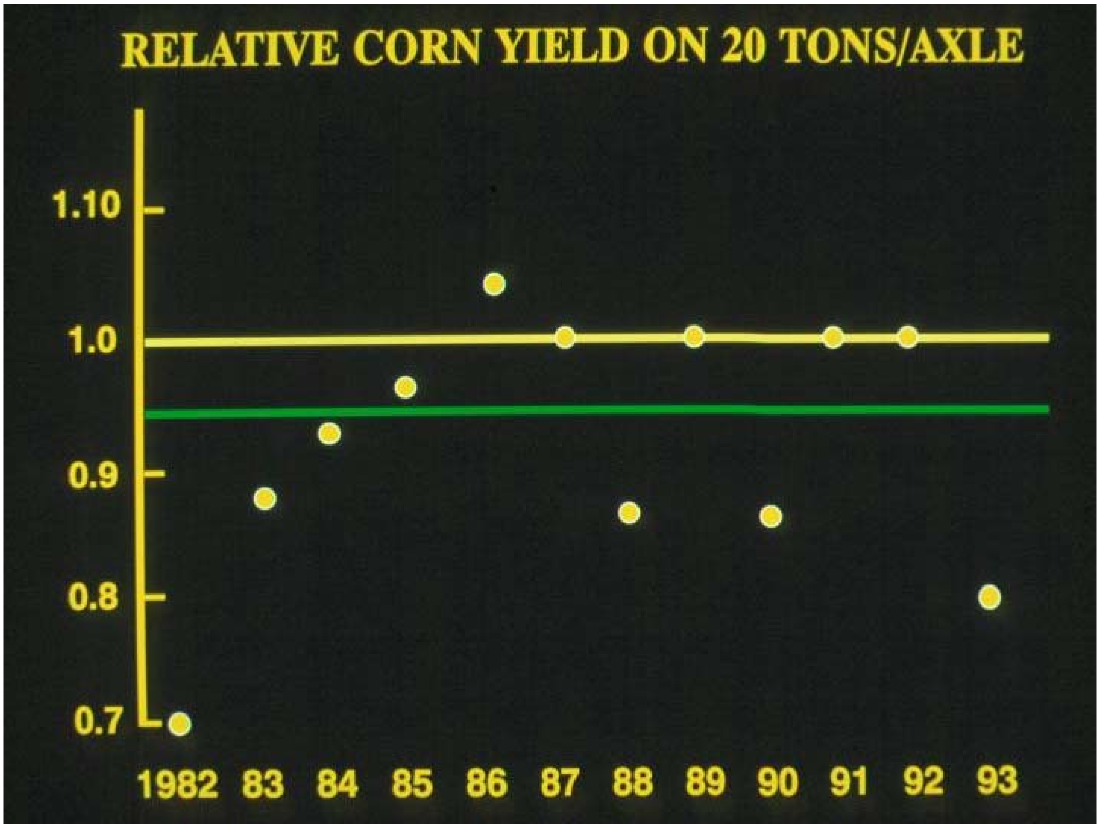

Figure 2. Relative long-term corn yield as affected by subsoil compaction.

tried to grow into the subsoil and extract water. 1990 and 1993 growing seasons were much wetter than normal, and residual subsoil compaction retarded drainage of excess subsoil moisture, causing aeration problems and 15-20 % yield reduction. That's after 12 years of freezing and thawing of soil subjected to a one-time 20-ton axle loading. Producers are doing this every year, often under wet, weak soils conditions. The data in Figure 2 suggests at least a 6% average "permanent" corn yield decrease due to compaction during common harvest operations.

Field data from Minnesota and Wisconsin suggests that for every percent decrease in corn height you can expect about a 1 percent decrease in corn yield.

The challenge of finding a workable compromise between large, time-efficient, but also heavy harvest and transport equipment is illustrated in Figure 3. A fully loaded 600-bushel grain cart with 30-inch wide tires on a single axle puts about 22 psi on the ground surface. To get the ground pressure down to a desired 10 psi would require a 30-inch wide track, 6 feet long. This can be done. But consider a 1,200-bushel cart. To get such a huge weight to exert a ground pressure of only 9-10 psi would require 30-inch wide tracks 12 feet long, and would likely cause maneuverability problems in the field. If producers continue to demand large heavy field machinery, industry will have to develop new concepts on how best to design and use large machinery without causing further yield decreases due to subsoil compaction.

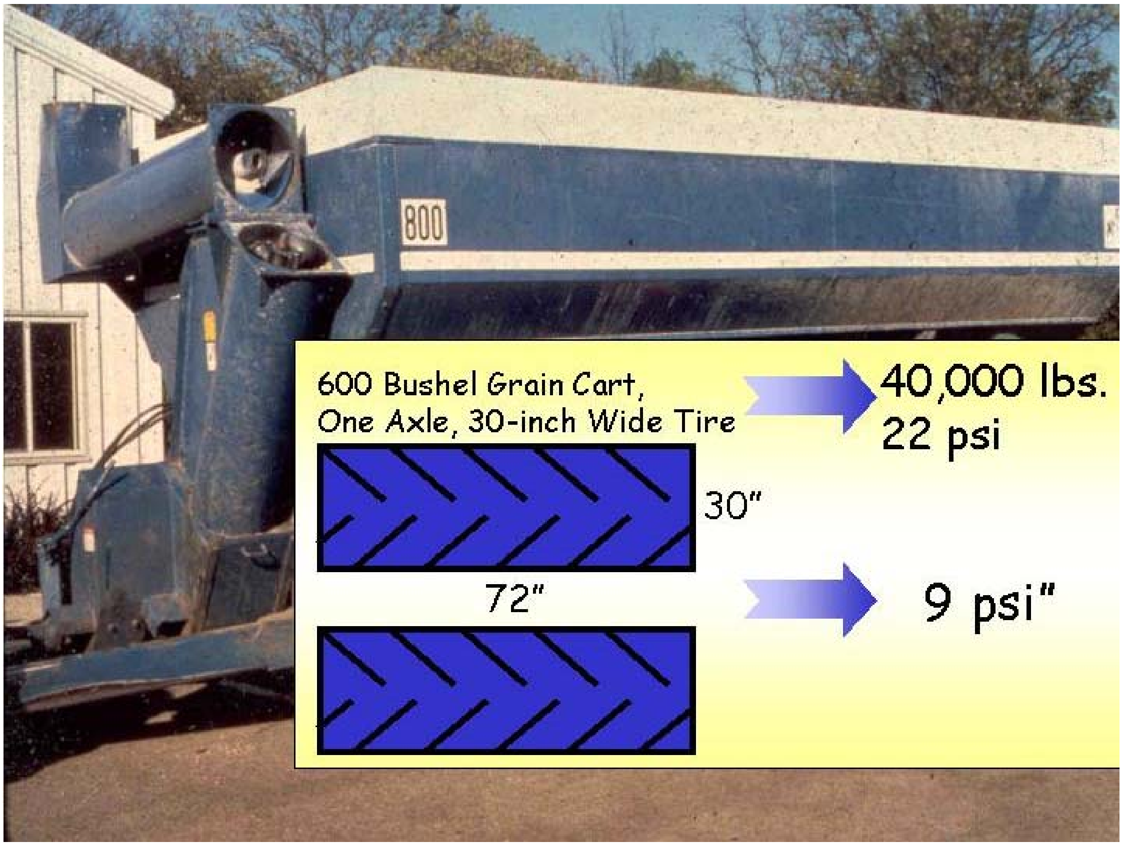

Figure 3. Ground pressure applied by grain cart.

Following are goals for managing wheel/track traffic to minimize soil compaction.

- Keep axle loads < 5 tons.
- Keep tire/track soil contact pressure < 10 psi.
- Keep bulk density < 1.3 g/cm^3.
- Keep penetrometer resistance < 200 psi (for root growth).

These threshold values should not be viewed as hard and fast, but rather as general goals to work towards. With large operations, it may be unrealistic to achieve these goals. Then minimizing the damage becomes essential, and the best way to do that is to practice controlled wheel traffic whereby all tire/track passes for every field operation occurs in the same path. The biggest challenge here is that the heaviest equipment (harvest and transport) is also generally the narrowest. But farmers have modified the wheel spacing on their grain carts to be the same as that of the combine. By pulling the grain cart in the same track as the previous pass of the combine, the percent of field subjected to heavy traffic is minimized. Large equipment generally means fewer wheel tracks per acre, which is good. It all depends on how the traffic is managed.